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Merging non synchronized data to establish a consistent state of a transmission network

How to deal with discrete phase-shifting transformer configurations

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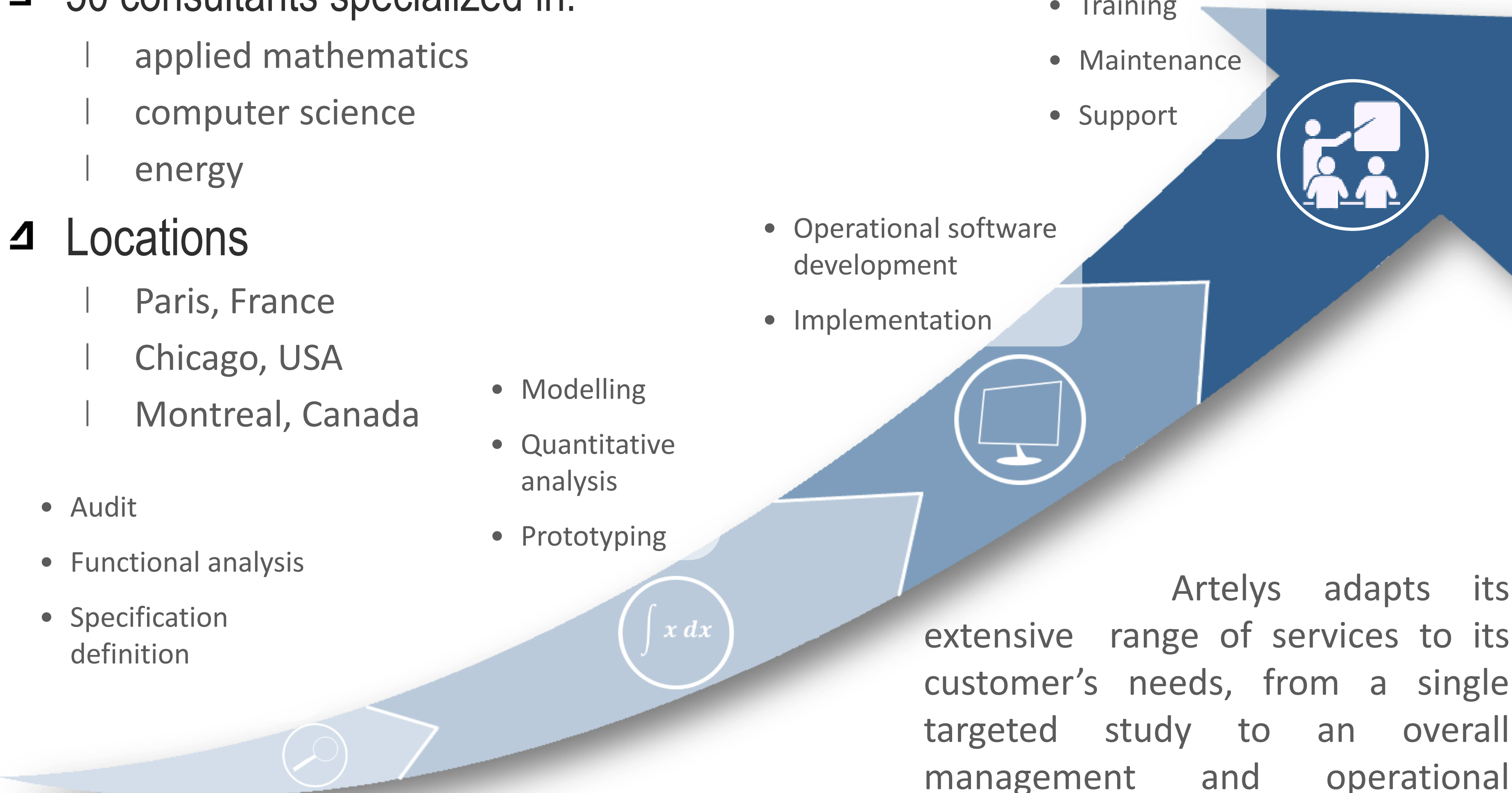
COMPANY OVERVIEW

- Independent company created in 2000
- 50 consultants specialized in:
  - applied mathematics
  - computer science
  - energy
- Locations
  - Paris, France
  - Chicago, USA
  - Montreal, Canada



- Audit
- Functional analysis
- Specification definition

- Modelling
- Quantitative analysis
- Prototyping

- Operational software development
- Implementation

- Training
- Maintenance
- Support

Artelys adapts its extensive range of services to its customer’s needs, from a single targeted study to an overall management and operational implementation of solutions.

CONTENTS

Introduction

- Merging data from different regions to establish a consistent state of the whole transmission network: Principle and Motivation.

Merging procedure

- The ideal case with correct synchronized data → Load Flow.
- The real scenario with missing and erroneous data → AC-OPF.

How to deal with discrete phase-shifting transformer (PST) configurations

- Correcting erroneous PST configurations implies to solve a Mixed Integer Non Linear Program (MINLP) due to the discrete configurations of PST.
- We develop a procedure using local violations of transmission lines thermal limits and a MPEC reformulation to solve this large scale MINLP.

Preliminary results

- Successful detection of phase-shifting transformer (PST) erroneous configurations on a European reconstructed network data set.

INTRODUCTION

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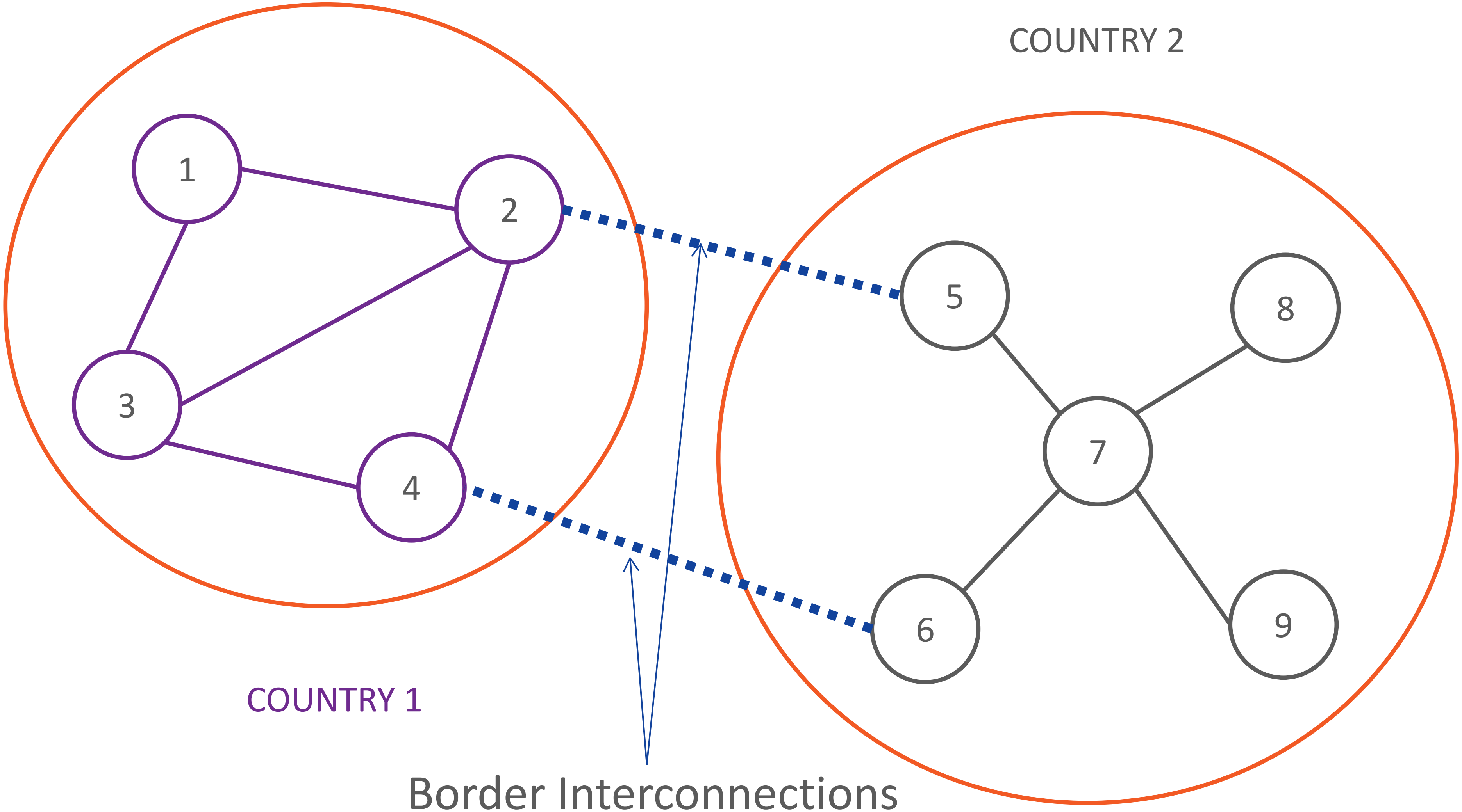
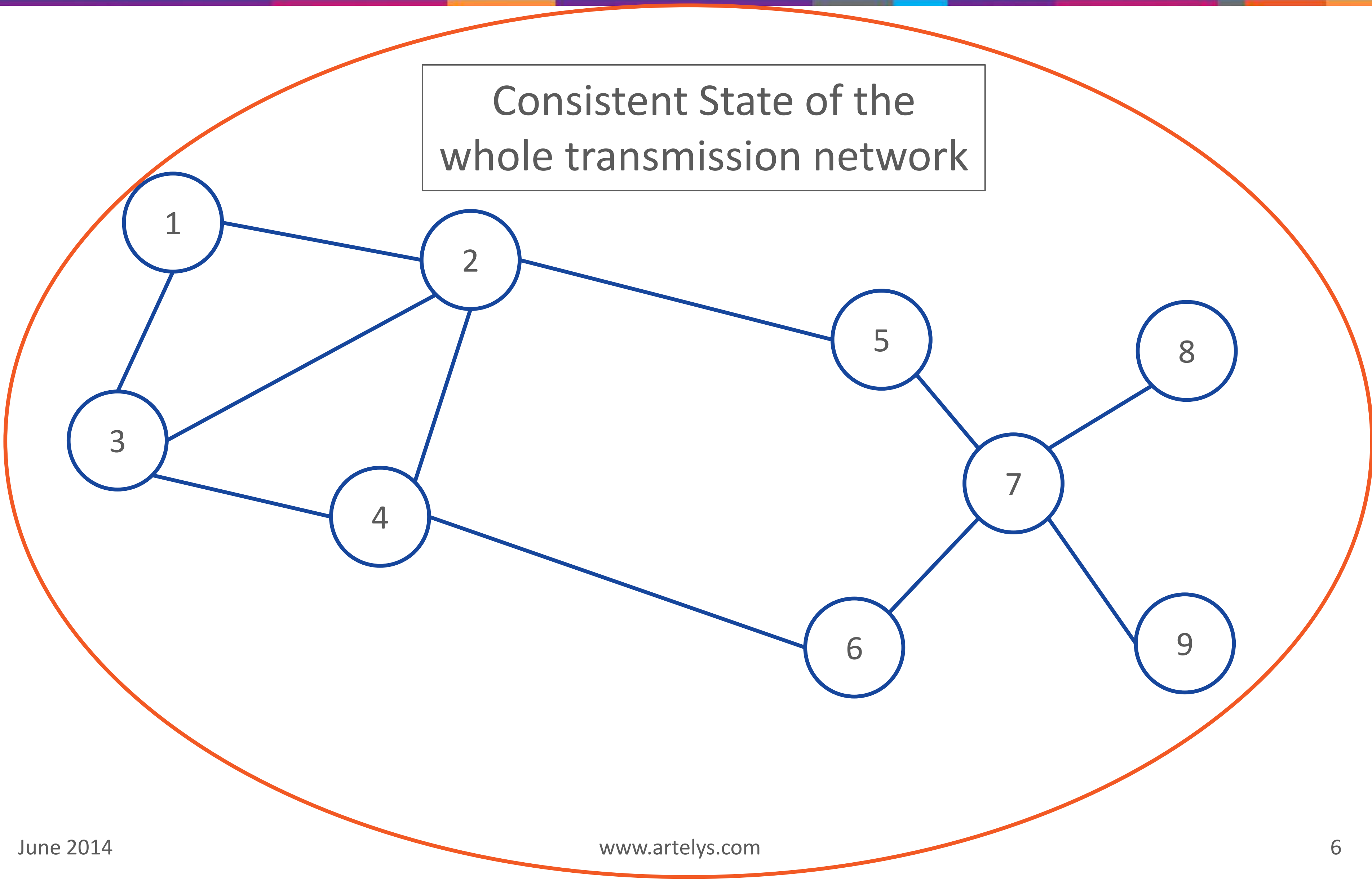


INTRODUCTION



INTRODUCTION

- A power system network is divided in connected region
  - Our study case is the European network which is divided in national networks linked by interconnections .
- Each region provides a description of its part in the global network
  - Generations (real power/reactive power).
  - Loads (real power/reactive power).
  - Power flow on border interconnections.
  - Voltage.
  - Phase-shifting transformer (PST) configurations.
- The aim is to build a description of the whole network
  - Merging topological description.
  - Building a consistent merged state
    - According to power flow equation.
    - With line thermal limits.

⇒ **Enable to run security analyses on the whole network.**

MERGING PROCEDURE

IDEAL CASE VS REAL CASE

- The ideal case
  - Each region provides:
    - No erroneous data.
    - Data that correspond to the exact same time.

A simple AC load flow enables to establish the state of the network.

- The real case scenario
  - Inhomogeneous data quality
    - Different modelling of power system devices in countries.
    - Data conversion limitations due to outdated exchange format.
  - Non synchronized data
    - Replacing unavailable data for the current time step by data from a previous time step.

Need to solve modified AC-OPF.

SOLVING THE REAL CASE SCENARIO

The mathematical model is a modified polar PQV AC-OPF

- Data provided by each region become targets
  - Loads (real / reactive) (P,Q)
  - Voltage magnitude (for PV node) (V)
  - Power flow on border interconnections (T)

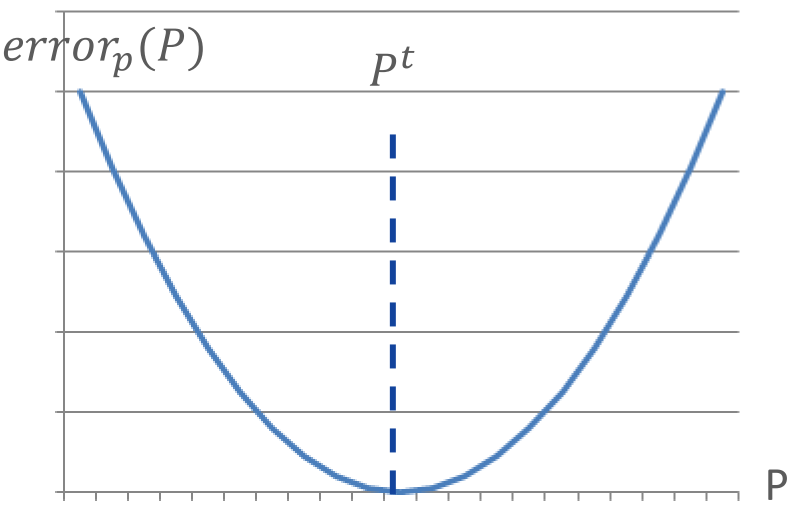
- Objective function
  - Minimizing the deviation to the targets.

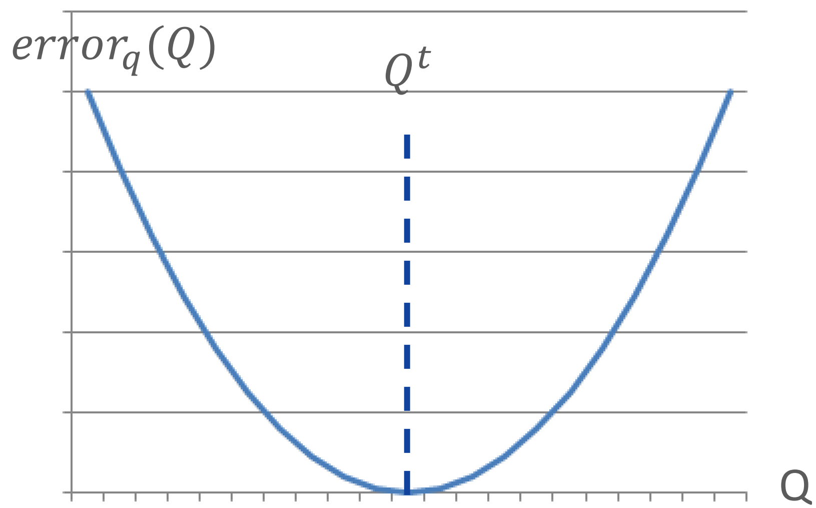
- Power system constraints
  - Fixed active power generations and voltage set points.
  - Operational constraints (Reactive limits on generations, PST operating states).
  - Complex Kirchhoff law at each node (nonlinear equality constraints).

PENALIZE LOAD DEVIATION

Quadratic penalization

- P^t, Q^t information provided by the country (Target).
- P, Q decision variables.
- $error_p(P) = (P - P^T)^2$ $\qquad$ $error_q(Q) = (Q - Q^T)^2$

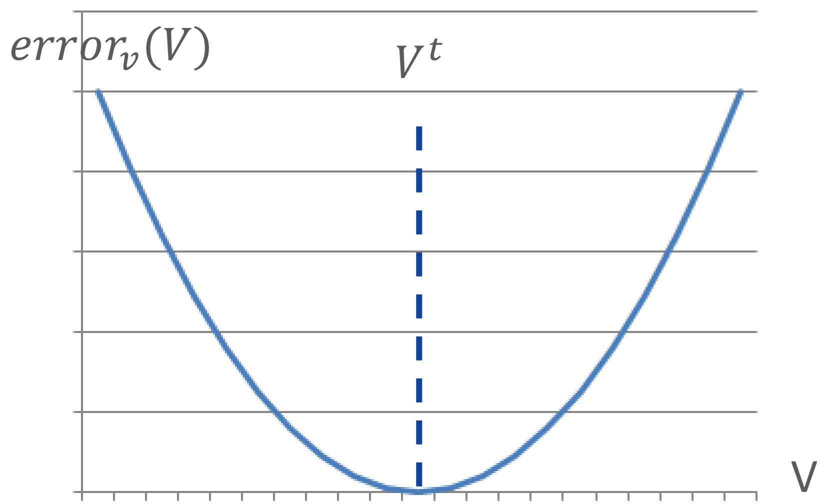




The optimal power flow will minimize the deviation to the targets.

PENALIZE VOLTAGE MAGNITUDE DEVIATION

- Quadratic penalization
  - V^t information provided by the country (Target).
  - V decision variable.
  - $error_v(V) = (V - V^T)^2$

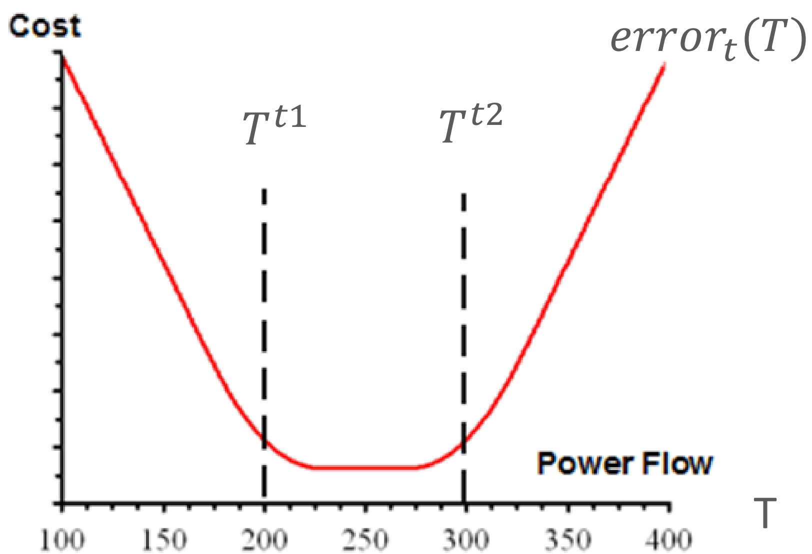


The optimal power flow will minimize the deviation to the targets.

PENALIZE TRANSIT DEVIATIONS ON INTERCONNECTIONS

The Huber function

- T^{t1} information provided by the first country.
- T^{t2} information provided by the second country.
- T decision variable.
- $error_t(T) = \rho(T - T^{t1}) + \rho(T - T^{t2})$



The optimal power flow on the border interconnection will be between the two values indicated by each country.

- A sum of weighted penalizing functions

$$\underset{P,Q,V,T}{Min:} \left\{ \begin{array}{c} \sum_{n \in nodes} Weight_n^p \cdot (P_n - P_n^t)^2 + \sum_{n \in nodes} Weight_n^q \cdot (Q_n - Q_n^t)^2 \\ + \\ \sum_{n \epsilon PV\ nodes} Weight_n^v \cdot (V_n - V_n^t)^2 \\ + \\ \sum_{i \in interconections} Weight_i^{t_1} \cdot \rho\left(T_i - T_i^{t_1}\right) + Weight_i^{t_1} \cdot \rho\left(T_i - T_i^{t_2}\right) \end{array} \right.$$

ρ = Huber Function

ACCORDING MORE IMPORTANCE TO RELIABLE DATA

Two types of data

- Synchronized information = Snapshot (SN).
- Non synchronized information = Day Ahead Congestion forecast (DACF)
  - ↳ 24 files per day.

Replacing strategy, independently for each country

Decreasing order of reliability

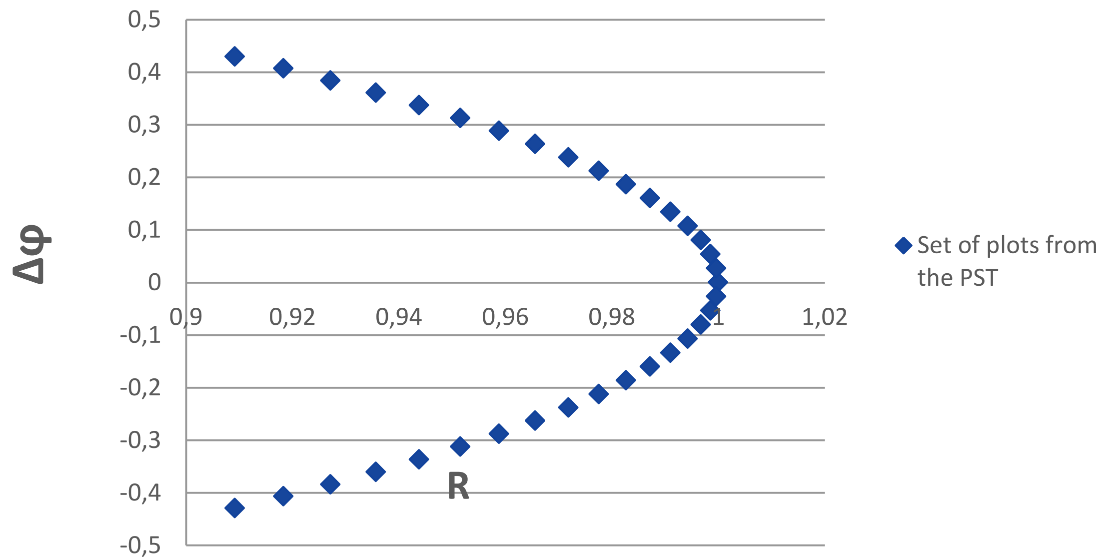
SN	DACF
DD:HH:MM	
DD:HH:MM – 15 min	
	H
	H-1 or H+1
	D-1 from Tuesday-Friday
	D-7 from Saturday-Monday
	Public holiday like Sunday

Increasing weight in the objective function

HOW TO DEAL WITH DISCRETE PHASE-SHIFTING TRANSFORMER CONFIGURATIONS

Phase-shifting transformer configuration

- Variables
  - R = Voltage Ratio.
  - Δφ = Phase-Shifting value (radian).
- Discrete set for (R, Δφ).



MINLP

$$R = \sum_{i \in setpoints} \lambda_i \cdot R_i$$

$$\Delta\varphi = \sum_{i \in setpoints} \lambda_i \cdot \Delta\varphi_i$$

$$\sum_{i \in setpoints} \lambda_i = 1$$

$$\lambda_i \in \{0,1\}$$

FROM NLP TO MINLP

- Case where PST configurations are reliable
  - PST configuration can be fixed to the information provided by each country.
  - The AC-OPF is then a Non Linear Program(NLP).
    - A direct approach by using commercial NLP solvers is able to deal with the continuous variables (P, Q, V, T).
    - Return a consistent state of the whole network close to the target configuration.

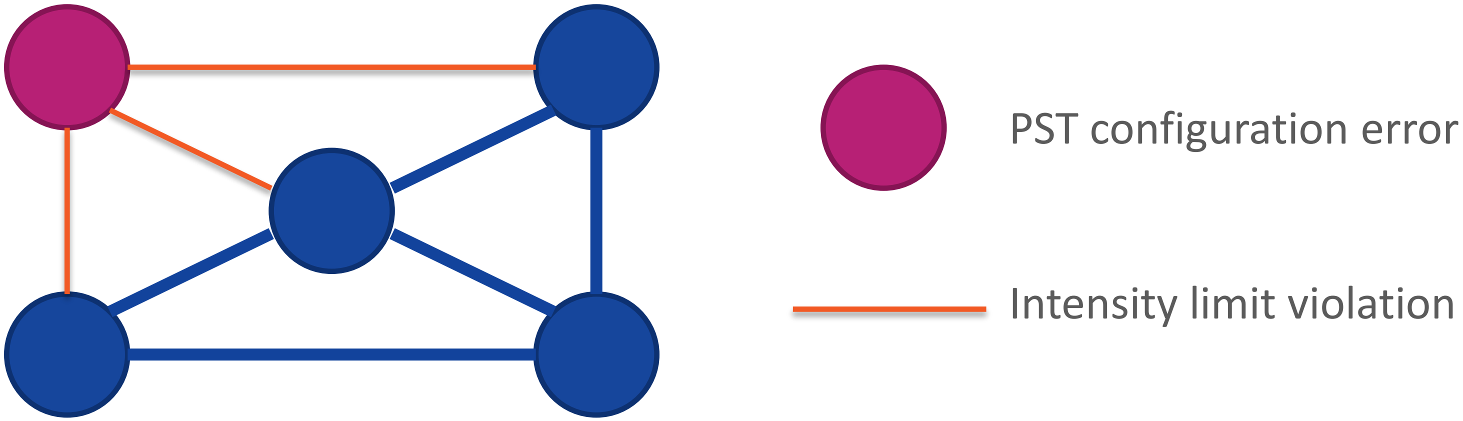
- Case where PST configurations contains erroneous or non-synchronized information
  - The AC-OPF become Mixed Integer Non Linear Program (MINLP).
    - A direct approach by using state-of-the-art MINLP optimization solver is not successful in finding the optimal solution with robustness due to the scale of the problem (7000 lines, 5000 nodes and 13000 discrete variables).

We develop a procedure using local constraint violations (thermal limits) to reduce the number of discrete variables.

RESTRICT THE NUMBER OF BINARY VARIABLES

Using transmission lines thermal limits

- Assumption: Load flows computed by each National TSO satisfy limits on intensity levels.
- Experience shows that an error in the PST configuration data at a node increases the intensity on transmission lines around this node.



Procedure

- 1. Run the AC-OPF model with PST configuration fixed to original input (NLP).
- 2. Detect intensity limit violations → Deduce all possible misconfigured PST.

CONTINUOUS RELAXATION

Continuous relaxation

MINLP

$$R = \sum_{i \in setpoints} \lambda_i \cdot R_i$$

$$\Delta\varphi = \sum_{i \in setpoints} \lambda_i \cdot \Delta\varphi_i$$

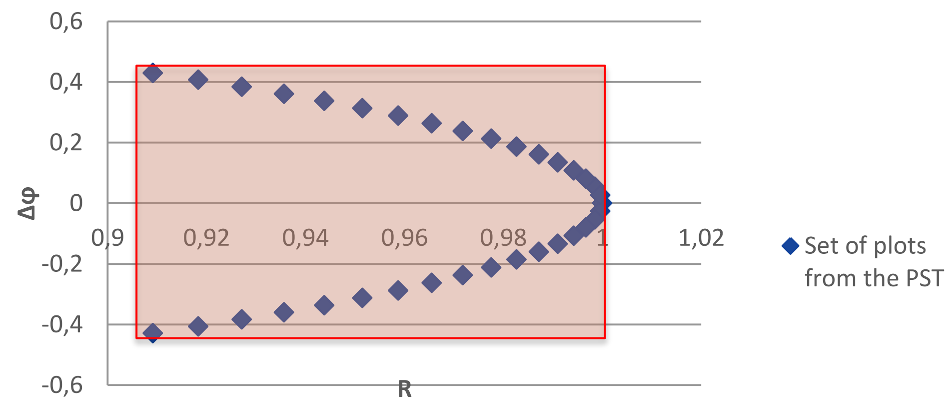
$$\sum_{i \in setpoints} \lambda_i = 1$$

$$\lambda_i \in \{0,1\}$$

Continuous relaxation

$$\min(R_i) \le R \le \max(R_i)$$

$$\min(\Delta\varphi_i) \le \Delta\varphi \le \max(\Delta\varphi_i)$$



Return a better initial PST configuration than the original input for the Mathematical Program with Equilibrium Constraint (MPEC).

MPEC reformulation

MINLP

$$R = \sum_{i \in setpoints} \lambda_i \cdot R_i$$

$$\Delta \boldsymbol{\varphi} = \sum_{i \in setpoints} \lambda_i \cdot \Delta \boldsymbol{\varphi}_i$$

$$\sum_{i \in setpoints} \lambda_i = 1$$

$$\lambda_i \in \{0,1\}$$

MPEC

$$R = \sum_{i \in setpoints} \lambda_i \cdot R_i$$

$$\Delta \boldsymbol{\varphi} = \sum_{i \in setpoints} \lambda_i \cdot \Delta \boldsymbol{\varphi}_i$$

$$\sum_{i \in setpoints} \lambda_i = 1$$

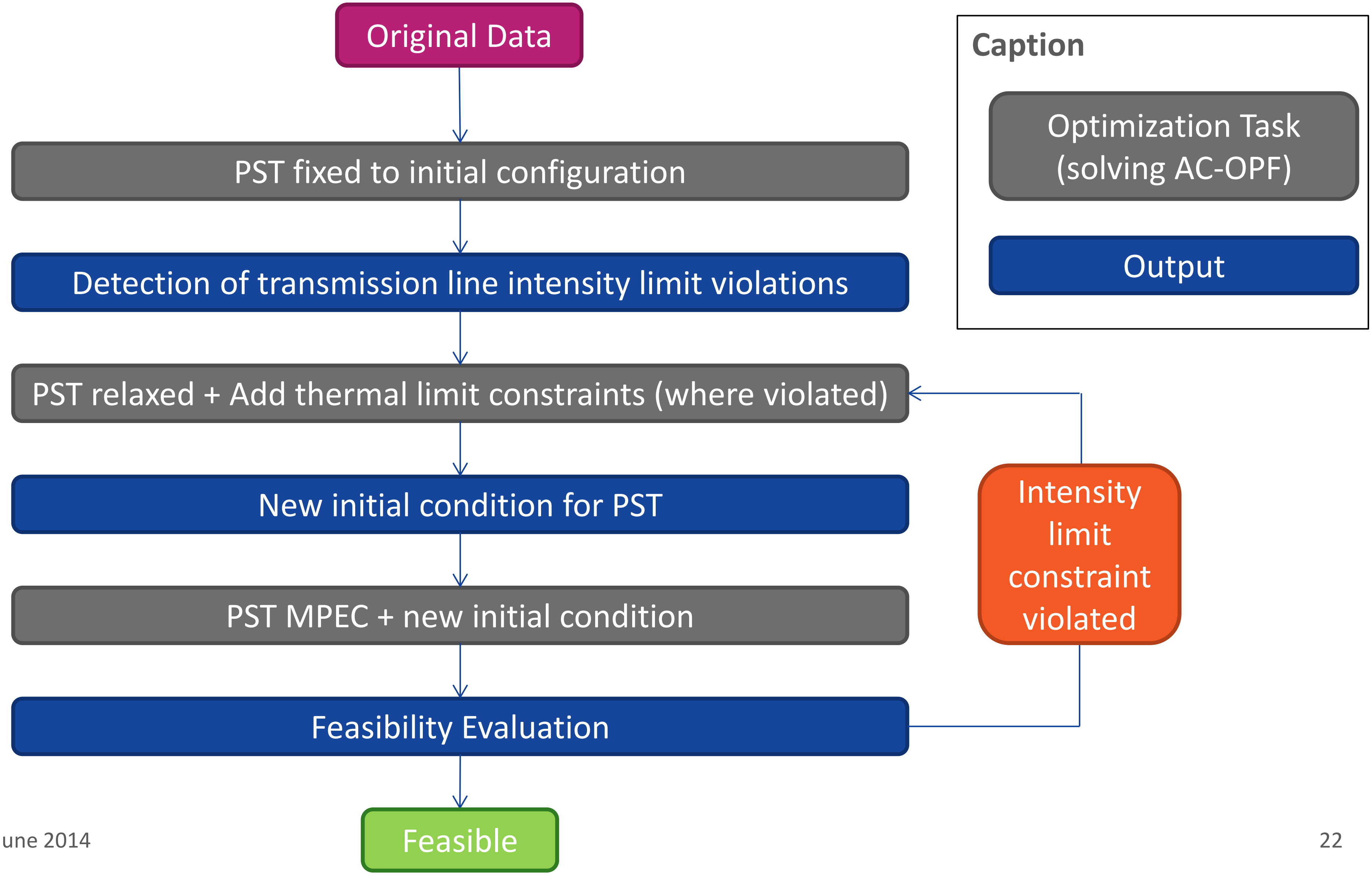
$$0 \leq \lambda_i \perp 1 - \lambda_i \geq 0$$

$$\min \text{objective} + \rho(\lambda_i \cdot (1 - \lambda_i))$$

$$\rho > 0$$

Penalty term

PROCEDURE USING LOCAL CONSTRAINT VIOLATIONS



PRELIMINARY RESULTS

STUDY CASE

Network

- A reconstructed data set from information of 11 European countries.
  - 7000 lines.
  - 5000 nodes.
  - 498 Transformers, 56 PST.

Data

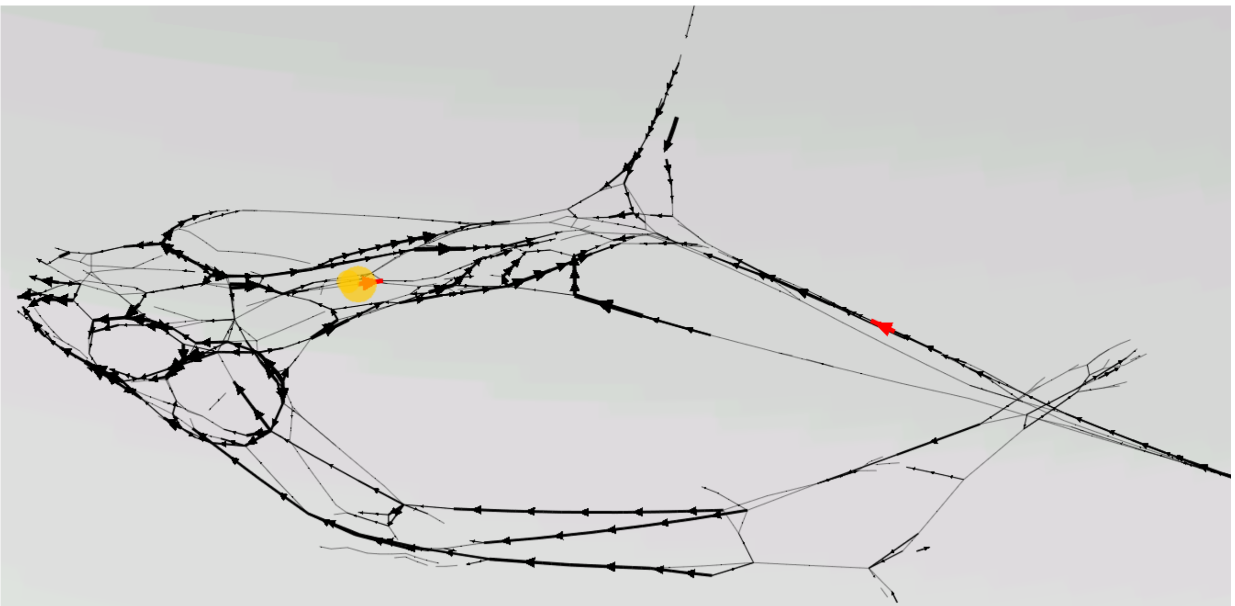
- 1 PST configuration error in the original data.
- 2 manually introduced errors on PST configuration.

Software

- KNITRO 9.0 - NLP solver (interior-point method and MPEC heuristic).
- AMPL - a standard modeling language for mathematical optimization.

Initial configuration

- Thermal limits violated on several transmission lines.



Representation of the European Network 220kV – 400kV

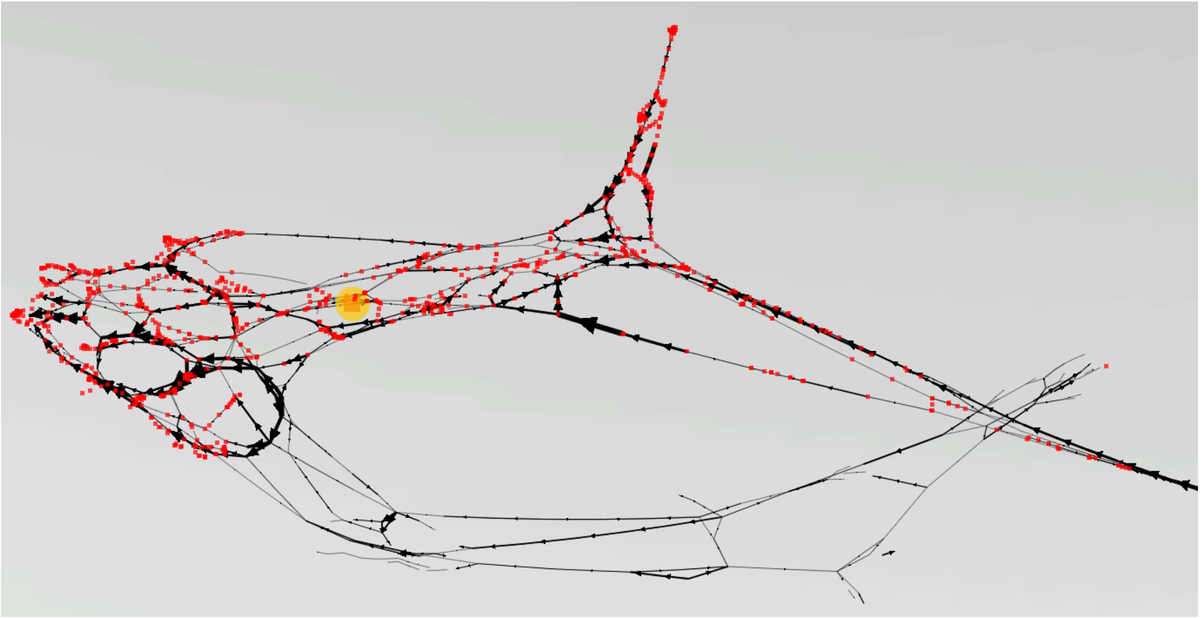
Real power flow

Thermal limits violated

Voltage magnitude further than 1kV from the initial value (Maximal gap: 2kV)

Initial configuration with thermal limit constraints

- Respecting thermal limit constraints shifts real power loads.



Representation of the European Network 220kV – 400kV

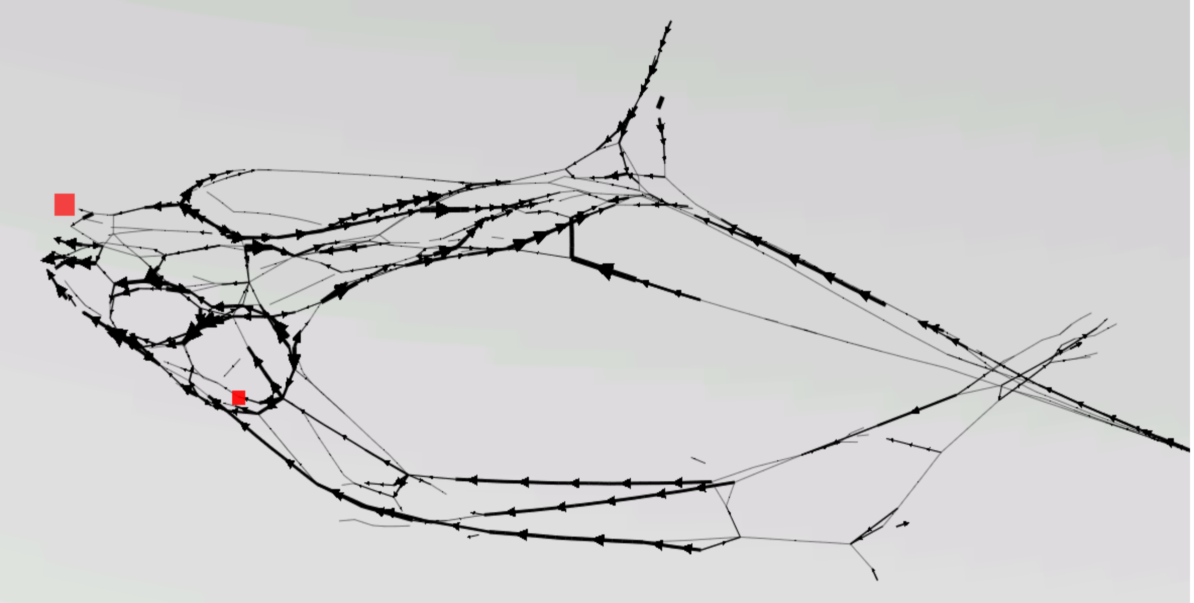
Real power flow

Loads further than 1MW from the initial value

Voltage magnitude further than 1kV from the initial value (Maximal gap: 2kV)

Final configuration: a feasible state

- Thermal limits are respected on all the transmission lines.



Representation of the European Network 220kV – 400kV

Real power flow

Loads further than 1MW from the initial value

The erroneous PST configurations were successfully corrected

CONCLUSION

CONCLUSION

- Merging data from different regions is required to run security analyses on the whole network.
- Merging non synchronized and erroneous data to establish a consistent state of the whole transmission network requires solving a modified AC-OPF model.
- A procedure using local constraint violations (thermal limits) has been developed in order to deal with discrete phase-shifting transformer configurations.
- The MPEC heuristic implemented in KNITRO 9.0 enables to treat the remaining discrete variables.
- Extension of this work is ongoing on a larger set of study cases for industrial integration.

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Thank you for your attention.

Feel free to ask questions.

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